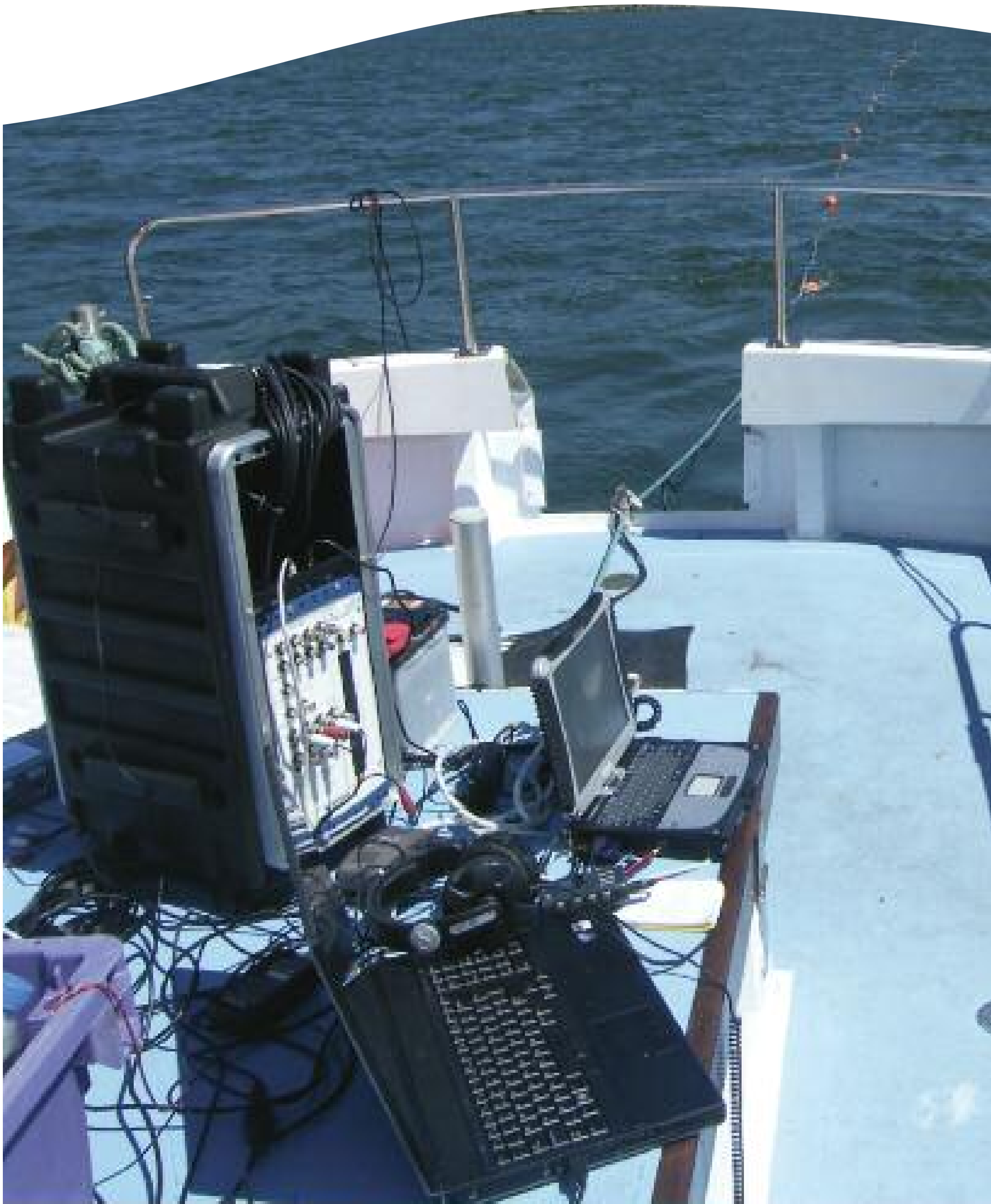
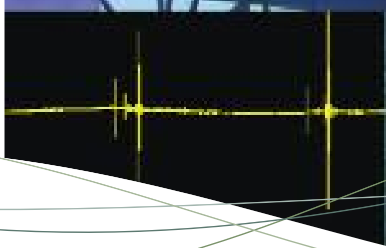
Marine Research Sub-Programme
(NDP 2007–’13) Series

Acoustic Based Cetacean Detection

Industry-Led Award, Final Report

SeaChange
Casadh na Taoide





Lead Partner: Biospheric Engineering Limited

Author: Eugene McKeown

NDP
National Development Plan
Transforming Ireland

Marine Institute
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"to undertake, to co-ordinate, to promote and to assist in marine research and development and to provide such services related to research and development that, in the opinion of the Institute, will promote economic development and create employment and protect the marine environment" Marine Institute Act 1991.

Sea Change: A Marine Knowledge, Research & Innovation Strategy for Ireland

Sea Change—A Marine Knowledge, Research & Innovation Strategy for Ireland 2007-2013—was launched in early 2007 and was the outcome of extensive analysis and consultation with government departments, state agencies, industry and the third-level sector. It outlines a vision for the development of Ireland's marine sector and sets clear objectives aimed at achieving this vision, namely to:

1. Assist existing, and largely indigenous, marine sub-sectors to improve their overall competitiveness and engage in activity that adds value to their outputs by utilising knowledge and technology arising from research.
2. Build new research capacity and capability and utilise fundamental knowledge and technology to create new marine-related commercial opportunities and companies.
3. Inform public policy, governance and regulation by applying the knowledge derived from marine research and monitoring.
4. Increase the marine sector's competitiveness and stimulate the commercialisation of the marine resource in a manner that ensures its sustainability and protects marine biodiversity and ecosystems.
5. Strengthen the economic, social and cultural base of marine dependant regional/rural communities.

The Sea Change strategy was developed as an integral part of the government's Strategy for Science, Technology and Innovation (SSTI) and the Marine Institute as the lead implementation agency is working within SSTI policy and with government departments and agencies to deliver on the Strategy.

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Marine Research Sub-Programme 2007-2013

Industry-Led Award

Acoustic Based Cetacean Detection

(Project reference number ILA/07/08)

Lead Partner:	Biospheric Engineering Ltd.
Author:	Eugene McKeown
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Biospheric Engineering ltd
PARTNERS IN SUSTAINABLE DEVELOPMENT

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1. Project Summary

Biospheric Engineering Ltd. is a small environmental noise consultancy company, based in the west of Ireland. Since 2004, they have been developing and extending underwater noise monitoring capabilities for a wide range of projects that generate underwater acoustic signals. Apart from the engineering aspects of the work, it is apparent that significant knowledge of biological sounds and sources are required to enable commercial services and products to be developed around the capability.

The Acoustic Based Cetacean Detection project has the twin goals of increasing the company's expertise and capability in underwater acoustics and developing a working system for cetacean detection. The objectives of the research were to:

- Identify the physical parameters associated with monitoring, tracking and positioning of marine mammals, principally cetaceans (whales and dolphins).
- Establish links with acoustic experts and monitoring systems equipment providers to critically review relevant hardware and software options and define a detection system based on available components.
- Maximise the use of available equipment and integrate existing signal processing tools into a practical small-scale detection system.
- Utilise the proposed small-scale system to demonstrate that the presence of specific marine mammals within a defined radius in shallow waters can be detected reliably.

Initial research focused on establishing the frequency spectrum of vocalising marine mammals and the equipment required to detect such sounds underwater. This included attending Marine Mammal Observer training workshops and attendance at conferences on underwater noise in the UK and Italy. Through attendance at these events a number of contacts were established with both equipment suppliers and academic researchers.

Due to the wide range of cetaceans found in Irish waters, the frequency spectrum of interest covers the range from 10 Hz to 150,000Hz. This extensive range has consequences for all of the equipment required—hydrophones to detect the sounds and convert the signal into a voltage, analogue to digital converters to digitise the signals and software to analyse very large datasets in real time to allow localisations to be carried out.

Desk studies were carried out on various equipment options to determine the optimum combination of equipment required for the project. Hydrophones (like microphones) tend to be designed for a particular frequency range. Seven types of hydrophone were tested to determine optimum frequency range and sensitivity. Five types of analogue to digital converter were assessed under different operating conditions and hardware configurations to measure performance and power requirements. A combination of sampling rate and bit rate were assessed to optimise the detection of different species.

Two software packages for localisation were tested using a calibrated acoustic pinger. Trials on marine mammals were constrained by difficult weather conditions. Although considerable time was spent on the water, the combination of vocalising marine mammals, fair weather and sufficient time in contact with the animals did not arise frequently enough for reliable confirmation to be obtained of localisation. Trials with the acoustic pinger were better controlled and carried out in appropriate weather conditions.

Three of the four primary objectives have been achieved. For operational reasons, testing has indicated that no one configuration can detect and localise all species. A number of systems have been developed and testing and optimisation of the alternate configurations will continue under operational conditions into the future. The company has gained valuable experience in underwater acoustics and the selection and operation of a wide range of equipment.

As a direct result of this project, the company has begun working with IBM and the Marine Institute on SmartBay Galway[1], with the potential for future collaborations on other underwater acoustics projects currently under discussion.

Finally, the Acoustic Based Cetacean Detection project forged strong links with another Marine Institute funded project – a three-year project entitled Policy & Recommendations from Cetacean Acoustics, Surveying and Tracking (PreCAST), being carried out by the Irish Whale & Dolphin Group (IWDG) and the Galway Mayo Institute of Technology (GMIT). The objective of PreCAST was to support cetacean conservation policy and the implementation of national and international obligations and build national capacity in the area of automated assessment and monitoring of marine mammals. This collaboration involved assessment of passive acoustic monitoring (PAM) techniques, estimating detection distances of cetaceans using various devices and developing a protocol for best practices in using the instruments. Both projects complemented each other and frequently shared resources and boat time.

[1] www.marine.ie/home/services/operational/SmartBay

2. Project Description

Underwater acoustic noise measurement is in its infancy in Ireland. The scope of this project was such that in addition to assembling and testing a cetacean detection system, the company developed wide-ranging capability in underwater acoustics and established relationships with equipment manufacturers and researchers from around the world. The field testing of different hydrophones, analogue to digital converters and software packages provided the means to assemble appropriate systems for various detection tasks.

Although recordings of marine mammals have been made previously, they have been carried out using basic equipment. No calibration of hydrophones or assessment of the impact of anthropogenic noise on aquatic life has been done in Irish waters. This project bridges these gaps. By carrying out objective, quantified underwater noise measurements, it is possible to determine the area of impact of the noise. By being able to localise animal sounds it is possible to determine if the animals are within the impacted area.

This project provided the means to detect and identify various species of marine mammals—some of whom were recorded for the first time in Irish inshore waters. It also developed the means of localising the source of the sound.

A comprehensive desk study of hydrophone types was carried out to determine the most suitable types for testing. Biospheric Engineering Ltd. started the project with three different hydrophone systems with varying sensitivities and frequency ranges. This permitted the detection of all species of cetacean but was limited in application to operating one hydrophone type at any time. In order to detect high frequency echolocation clicks[2] and low frequency vocalisations[3] at maximum sensitivity it was necessary to use two different hydrophones simultaneously. The project involved testing seven types of hydrophones and working with three different hydrophone manufacturers to optimise hydrophone design. The hydrophones tested include units from Bruel & Kjaer, RESON, HiTech, Geospectrum Technologies and Cetacean Research.

By testing several analogue to digital conversion options, the optimum detection system for each species could be configured. It was also possible to configure a 'general' system that could cover all species. Testing included various PC sound cards, PCMCIA sound cards, USB audio

[2] See Appendix II for brief explanatory note.
[3] See Appendix II for brief explanatory note.

devices, ASIO firewire devices and industrial A/D converters. Units from Creative, Behringer, MOTU, Edirol, Avisoft and National Instruments were also tested in the field. For most low-frequency applications, PC sound cards are sufficient. For Harbour Porpoise detection, however, specialised high-frequency hydrophones and A/D equipment are required.

Two primary software packages were tested, *PamGuard* and *Ishmael*. *PamGuard* is a development (and incorporates all the essential features) of previous generation software such as *Rainbowclick* and *Porpoise*. As *Pamguard* is more up-to-date it was chosen in preference to testing *Rainbowclick* and *Porpoise*. Both *PamGuard* and *Ishmael* are used internationally by researchers, with *PamGuard* more prevalent in Europe and *Ishmael* in the USA. Contact has been established, and is still maintained, with the developers of both software programs.

The work performed on the project resulted in the following configurations:

1. Low-frequency large whale detection option using two hydrophones (bearing capability with left right ambiguity).
2. Mid-frequency dolphin detection using three hydrophones (bearing capability without ambiguity).
3. High-frequency porpoise detection using two hydrophones (bearing capability with left right ambiguity).
4. General system with broadband detection capability using two hydrophones (bearing capability with left right ambiguity).

All of these configurations comply with the project goals of being capable of deployment from a small boat (angling charter boat, Rigid Inflatable Boat or similar) for environmental assessments and mitigation purposes.

In addition to the knowledge gained in assembling and testing these configurations, the project resulted in:

- Establishing working relationships with leading acoustics researchers in the UK, USA, Italy, Spain, Canada and Australia. Regular email correspondence with these researchers provides an ongoing source of information for developing the system further and is an important component of the company's development into the future. This was a key deliverable of the project.
- Invitation to present a paper on cetacean detection the 2nd International Conference on the Effects of Noise on Aquatic Life.

- Establishing a working relationship with the SmartBay Galway team and setting up acoustic monitoring on the Mace Head buoy.
- Involvement with the American Standards Association committee, drafting a new standard for measuring underwater noise from ships in shallow water.
- Involvement in the European Science Foundation EMAR2RES project as an expert on the physical impacts of marine transport on the marine environment.

3. Results and Outcomes

As part of the project, the following training programmes and conferences were attended. This was an integral part of the project to ensure sufficient baseline knowledge and to establish links with international experts.

- Marine Mammal Observer training, Oceanear/University of Plymouth UK
- Conference on Underwater Noise Measurement, Impact and Mitigation, Institute of Acoustics, Southampton UK
- 4th International workshop on Detection, Classification and Localisation of Marine Mammals Using Passive Acoustics, University of Pavia, Italy
- *PamGuard* training, SMRU, University of St. Andrews Scotland

The initial phase of the project involved testing individual hydrophones with specific species to determine the optimum frequency range and sensitivity and to identify issues arising from the use of systems on small boats. It was immediately apparent that power systems on boats are prone to high frequency interference. To overcome this difficulty, the system was designed to run on its own isolated battery system. This introduces limits on deployment times but this, in turn, can be overcome by using multiple batteries.

In order to develop the localisation capabilities, testing of the system using pingers was carried out in Galway Bay. Due to the absence of marine mammals in the area, testing could be carried out using a known source level. This allowed testing of the optimum hydrophone array spacing to be carried out.

Testing of individual hydrophones was carried out off the Blasket Islands with Harbour Porpoise and Minke Whale; in the Shannon Estuary with Bottlenose Dolphins; in Donegal Bay with Bottlenose Dolphins; and off the south coast with Fin Whales, Humpback Whales, Common Dolphins and Harbour Porpoise. The majority of the testing was carried out in conjunction with the IWDG/GMIT group. This approach ensured accurate identification of species and a more or less guaranteed contact with marine mammals.

Weather conditions during 2008 and 2009 played a major role in determining how often contact was made with marine mammals. In order to reliably make contact it is necessary to have a period of reasonably settled weather, so that land-based sightings identify suitable locations. It is then necessary to mobilise a team at short notice to avail of weather windows.

It was an unfortunate coincidence that the only extended period of fine weather in 2009 coincided with the Volvo Ocean Race, when all charter boats on the west coast were in Galway for the event! Nonetheless, significant time on the water allowed for some significant results, including recording Humpback and Fin Whales in Irish inshore waters for the first time. It had been thought that these species only vocalised on the breeding grounds in warmer water.

Localisation

In order to localise the source of a sound signal, a technique based on the Time Delay Of Arrival (TDOA) is used. Basically, this technique relies on the fact that the speed of sound is approximately 1,500m/s underwater. If two hydrophones are placed 1 metre apart, a signal coming from some distance away will arrive at the furthest hydrophone about 0.0007 seconds after it reaches the nearest hydrophone, similarly with multiple hydrophones. If the location of the hydrophones is known, it is possible to calculate the location of the sound source.

To do this accurately requires that the hydrophones are accurately positioned relative to one another and that the signal is simultaneously recorded on multiple channels connected to a PC with sufficient power that can run the localisation calculation. With modern A/D devices and PCs this can be done in a relatively straightforward manner. Software such as *PamGuard* or *Ishmael* can run the calculation in 'real time', i.e. within a second or so of acquiring the signal.

With twin-towed hydrophones it is possible to determine a hyperbola on which the sound source is located. This provides an indication of the bearing of the source, but as there are only two known points (the hydrophone locations) it is only possible to identify the location with what is known as a left-right ambiguity, i.e. we cannot be certain which side of the hydrophones the source is located. In fact, the source could be anywhere on a 3-d hyperbolic surface surrounding the hydrophones. In shallow water it might be possible to eliminate one of the options as improbable due to water depth or land location. In deeper water, by turning the vessel slightly, it is possible to determine where the bearings are converging. For towed hydrophones in linear arrays, it is not possible to determine 3-d location even if several hydrophones are utilised. As it is difficult to tow anything other than a linear array of hydrophones, considerable time was spent on the project using static arrays with non-linear configurations. With such configurations it is theoretically possible to localise the sound source in 3-d.

Trials using two hydrophones and a pinger (61 kHz at 1 second intervals) were carried out at Moneypoint jetty. Using two hydrophones it is only possible to estimate the left-right bearing set. As can be seen in Figure 1, these resulted in localisations at 126 and 334 degrees. As 334 degrees was directly towards land from the measurement location the only sensible option was from the 126 degree location. The source for this trial was located 800 metres to the southeast of the hydrophone location, indicating that the system can operate reliably in the field.

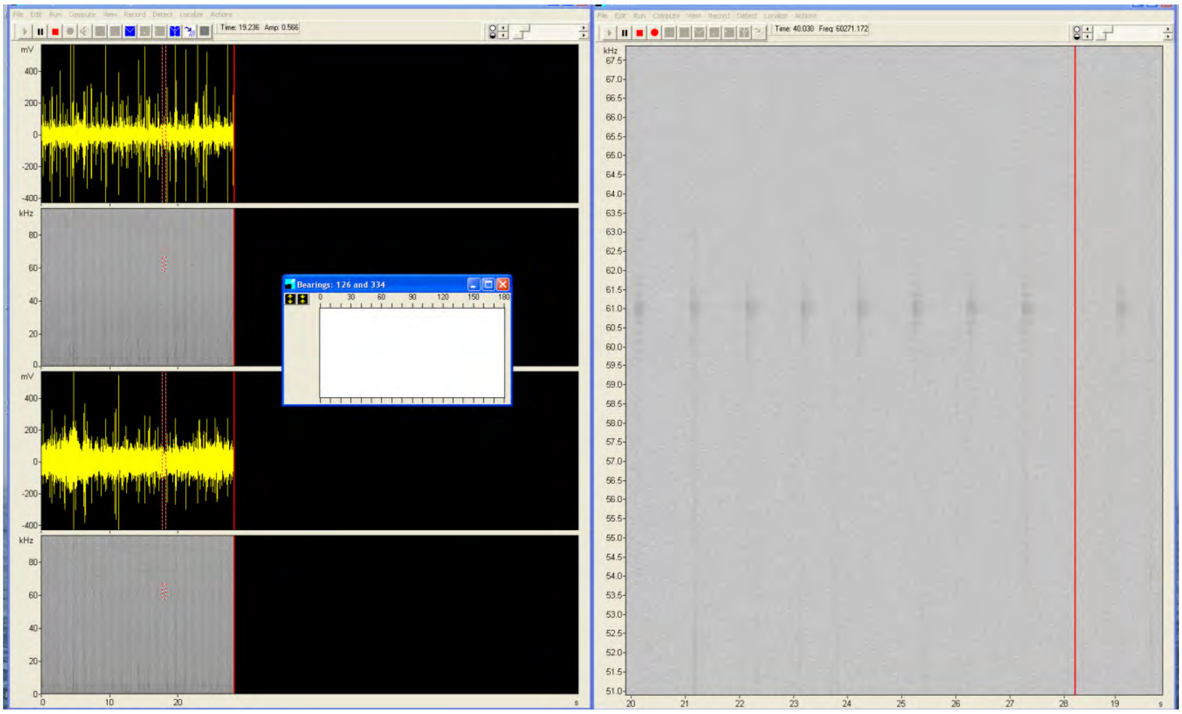


Figure 1 - Two hydrophones localisation

In order to assess the system under controlled conditions for full localisation, trials were carried out using reverse engineering. A three-track sound file was assembled from recordings of Common Dolphins. Based on TDOA calculations time-delays were imposed on the three tracks. *Ishmael* was then run in off-line mode analysing the sound file.

By using two hydrophone combinations to determine a left-right bearing set and a third to cross-correlate the bearings, the left-right ambiguity can be eliminated. In this case *Ishmael* correctly determined the direction of the source as 21 degrees, the pre-determined direction from the time delays. A series of files were put together for 21, 101, 164, 238 and 329 degrees. In each case *Ishmael* correctly predicted the single angle within 5 degrees accuracy.

The localisation outlined in Figure 2 is optimised for small inter-hydrophone spacing. Due to the close proximity of the hydrophones, it is not possible to accurately calculate a location for the sound source. The TDOA is of the order of 0.2 milliseconds, any small error in timing results in relatively shallow differences in bearing angles and thus significant variation in localisation of positions. In order to solve this it is necessary to have a large inter-hydrophone spacing, of the order of 3-6 metres. This could be achieved with a multi-hydrophone array where the hydrophones are clustered in groups of two or three at 3 metre intervals.

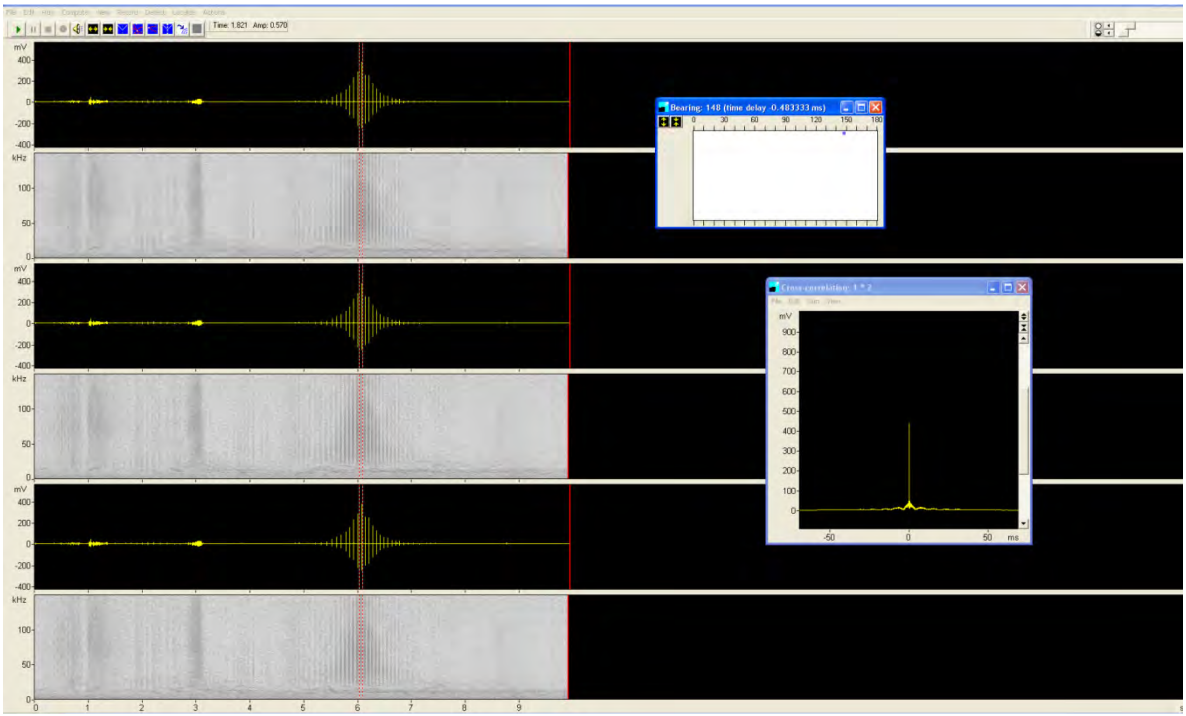


Figure 2 – Three hydrophones localisation

4. Impacts and Benefits

This project has established Biospheric Engineering as a leading underwater noise consultancy company, with what was a small specialist part of an acoustic consultancy now grown to be the major source of their business. This specialisation has permitted the company to continue to grow and invest. The expertise gained has led directly to involvement in SmartBay Galway and discussions are taking place regarding an involvement in the Wave Energy Test Sites off the West Coast.

As an industry-led programme, it is vital that the project results in a commercial benefit to the company. Participation at international conferences and training programmes has provided significant information on the opportunities available for commercialisation of the technology developed. Exposure to what is happening internationally provides a broad perspective on the underwater acoustics business, while at the same time highlights specific niche markets that can be targeted.

Specific benefits to the company include:

1. Underwater acoustics capability increased significantly—Biospheric Engineering are now established as the leading service provider in Ireland, have already completed work in Northern Ireland and are seeking work in the UK and Europe with strategic partners.
2. Extensive experience has been gained under a wide range of sea conditions and operating platforms. Having the funding and support of the Marine Institute facilitated a steep learning curve on a vital skillset.
3. Directly related commercial opportunities gained in 2009 amounted to 10% of the project value, which is expected to increase to 35% of the project value in 2010. This represents a rapid return on investment for the company.
4. New commercialisation opportunities have been developed and links established with bodies such as the American Standards Association and the European Science Foundation, who have specific interests in underwater noise.
5. Biospheric Engineering Ltd has joined the SmartBay Galway team to develop a passive acoustic monitoring system for deployment on a permanently moored buoy. The system is being developed in conjunction with IBM's Big Green Innovations group and utilises Intel's WiMax wireless communication technology. It will be deployed initially on the SmartBay buoy at Mace Head.

6. Further partnerships to develop a noise monitoring and analysis system for application in a number of sectors, including offshore energy and maritime transport/security, are at an advanced stage. It is hoped that this will further develop capacity (and jobs) in the field of high-frequency signal analysis, communications and design, and construction and deployment of marine buoys.
7. Participation by Biospheric Engineering Ltd in these projects will facilitate the development of further technical solutions that have international application in a rapidly growing market.

Appendix I: Company Description

Established in 1999, Biospheric Engineering Ltd. has developed an underwater noise capability including calibration to international standards. With a combined 30 years experience in acoustics and vibration, and innovative and accurate monitoring, solutions have been developed for a wide range of infrastructure projects. From our base in Bearna, Co. Galway we are proud of our strong client focus and long-term relationships. Our aim is to work with our clients, develop a deep understanding of their requirements and produce comprehensive and cost-effective solutions.

The company was founded by Eugene McKeown, who is a Chartered Engineer with qualifications in Mechanical Engineering, Law and Acoustics, in addition to extensive experience in acoustic measurement, impact prediction and mitigation. He has extensive marine experience including certification for commercial powerboat operation and is a qualified Marine Mammal Observer. Wide ranging capability, attention to detail, allied with years of industry experience make us the choice to partner with for difficult marine environmental projects.

CAPABILITIES

1. Environmental Impact Studies

Biospheric Engineering Ltd. has carried out over 300 Environmental Impact Studies, including large windfarm, energy infrastructure, wastewater treatment, SONAR and seismic surveys and port developments. We have the capability to measure background noise levels from 1 Hertz to 650 kiloHertz, which covers the full spectrum of underwater noise events.

2. Impacts on all Marine Species

Anthropogenic underwater noise is regarded as a marine pollutant under the Marine Strategy Framework Directive and the OSPAR Convention. Underwater noise can have a range of impacts from fatalities to short-term behaviour responses in both marine mammals and fish. By analysing the frequency, intensity and duration of noise sources, this impact can be assessed on a species-specific basis.

3. Equipment Calibrated to Traceable International Standards

Our hydrophones can be field calibrated using a hydrophone calibrator. The measuring system can be calibrated by means of calibrated signal injection. Both methods are traceable to international standards. This provides the means for inter-site comparison and range estimation on an objective basis.

APPENDIX II: MARINE MAMMAL VOCALISATIONS

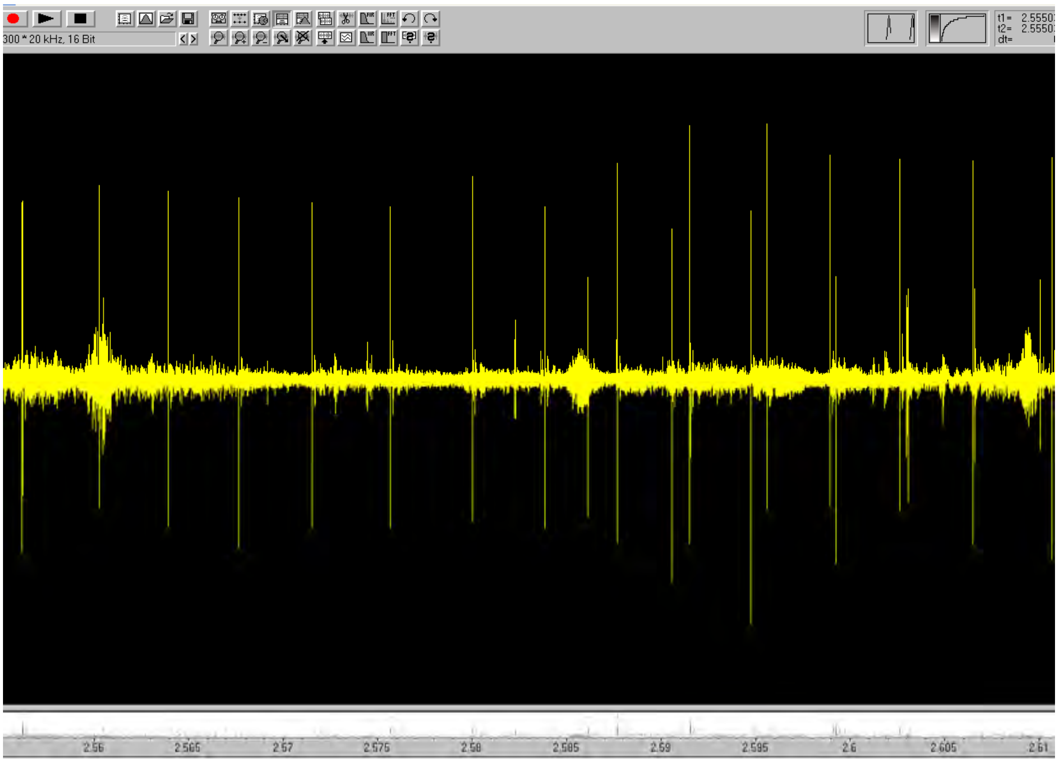
There are two principle types of marine mammal vocalisations: (1) Echolocation Clicks and (2) Other Vocalisations.

1. Echolocation Clicks

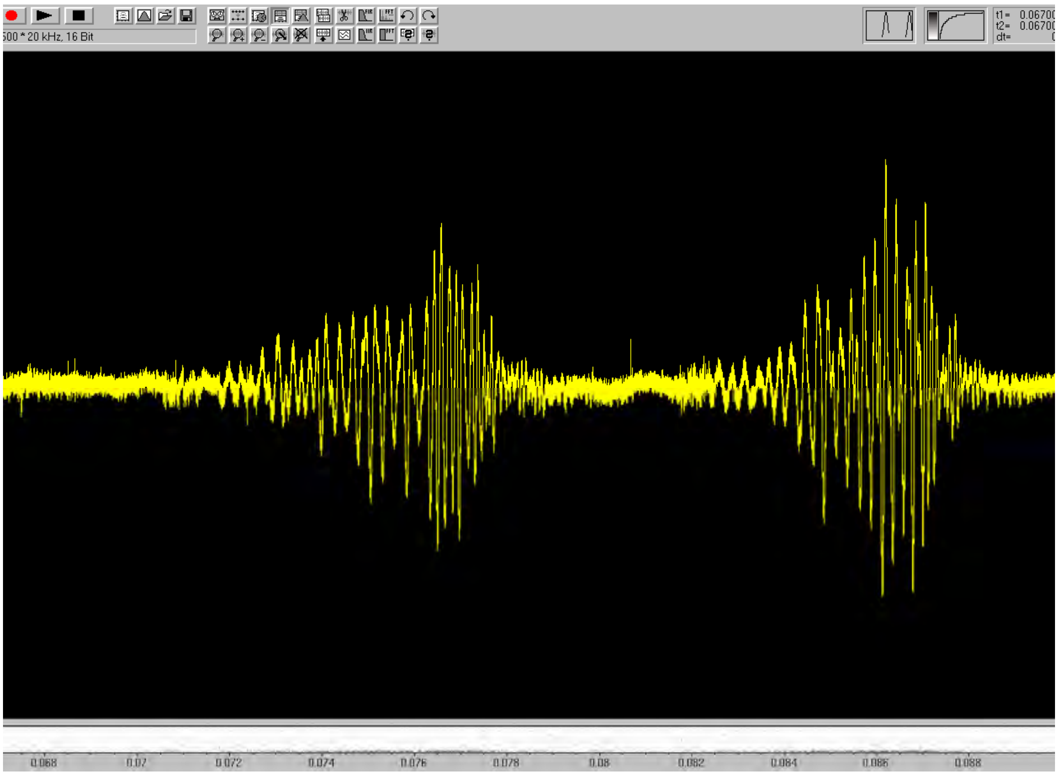
Echolocation clicks are generally high-frequency clicks of very short duration that are used in a manner similar to bats, to identify spatial location and to target food. In most cases, echolocation clicks consist of a series of clicks with very short inter-click intervals. The sounds are quite loud but because they are at high frequency, tend to attenuate rapidly with distance in the water. This makes them very identifiable but for localisation, the short inter-click interval can make it difficult to identify individual clicks on multiple track recordings to enable localisations to be carried out. The solution to this problem is to reduce the hydrophone array spacing to a minimum, thus shortening the time delay of arrival and enabling the same click to be identified on each track.

2. Other Vocalisations

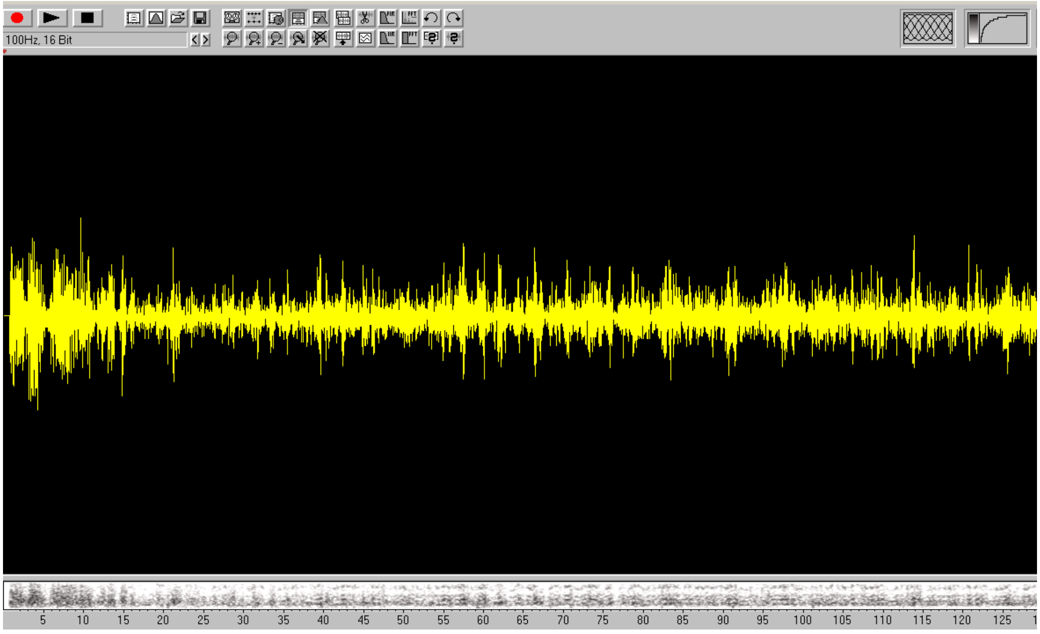
Other vocalisations can comprise of whistles (in the case of dolphins) and moans or grunts in the case of other species. These vocalisations are generally longer in duration, at lower frequency and detectable at longer distances. Using them for localisation is more problematic, however, as the time of arrival of the signal is less certain than is the case with an echolocation click. Very low-frequency vocalisations, such as that from Fin Whales, can be difficult to pick up as they lie in the same frequency range as background noise. The signal is, however, highly characteristic and, therefore, relatively easily identified. Some examples of vocalisations are included below:



Common Dolphin Echolocation Clicks



Grey Seal Vocalisation



Fin Whale Vocalisation

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